Instability Growth Seeded by D-T Ice Density Perturbations in ICF Capsules

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Introduction

Inertial Confinement Fusion on the National Ignition Facility uses laser energy to compress fuel pellets. The implosion process is highly unstable, so even minute imperfections can grow very large at maximum compression and disrupt the fusion process.

Many sources of instability have already been examined, including the gas fill tube, support tent, surface roughness of the ablator and ice, and even density fluctuations in the ablator as a result of oxygen absorption[1-4].

In this work we explore ice density fluctuations as another possible instability source. These are characterized both by the reaction yield with perturbations present, as well as by measuring the size of the perturbations during the implosion. Finally, we test mitigation of instabilities in the ice by seeding corresponding perturbations in the ablator.

Method

Simulations: The hydrodynamics code ARES was used for this work. These simulations were run in 2D with cylindrical symmetry. The ice was perturbed by a simple cosine function with m wavelengths around the circumference of the capsule, where m is the mode number. The inner ice surface was used for surface perturbations, and the bulk of the ice was used for density perturbations (see Fig. 1).

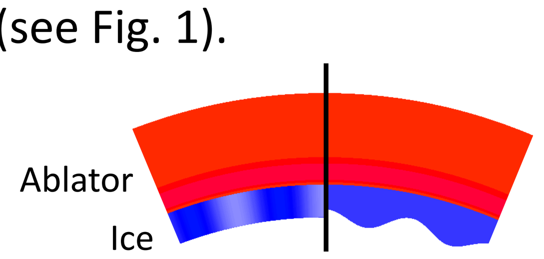

Fig. 1: Density of a capsule with perturbed ice density (left) and ice surface (right).

Growth Factor: To compute the growth factor, the density was integrated radially to obtain the column density ρR as a function of angle. This metric makes it possible to track mass as it shifts laterally across the surface of the capsule during the implosion and measure the instability size as a function of time. The growth factor was computed by comparing ρR at start time and time of peak velocity:

$$\text{growth factor} = \frac{\left[\frac{\rho R(RMS)}{\rho R(avg)}\right]_{t=peak}}{\left[\frac{\rho R(RMS)}{\rho R(avg)}\right]_{t=0}}$$

Ablator Compensation: We also investigated the feasibility of compensating ice perturbations with deliberate ablator perturbations of opposite phase.

Results

Reaction Yield

For low modes, ice density and surface perturbations behave very similarly. However, for realistic surface roughness amplitudes[1] of 3%, the perturbations do not grow enough to severely reduce the yield (see Fig. 1). The most damaging of the low modes is found to be mode 12.

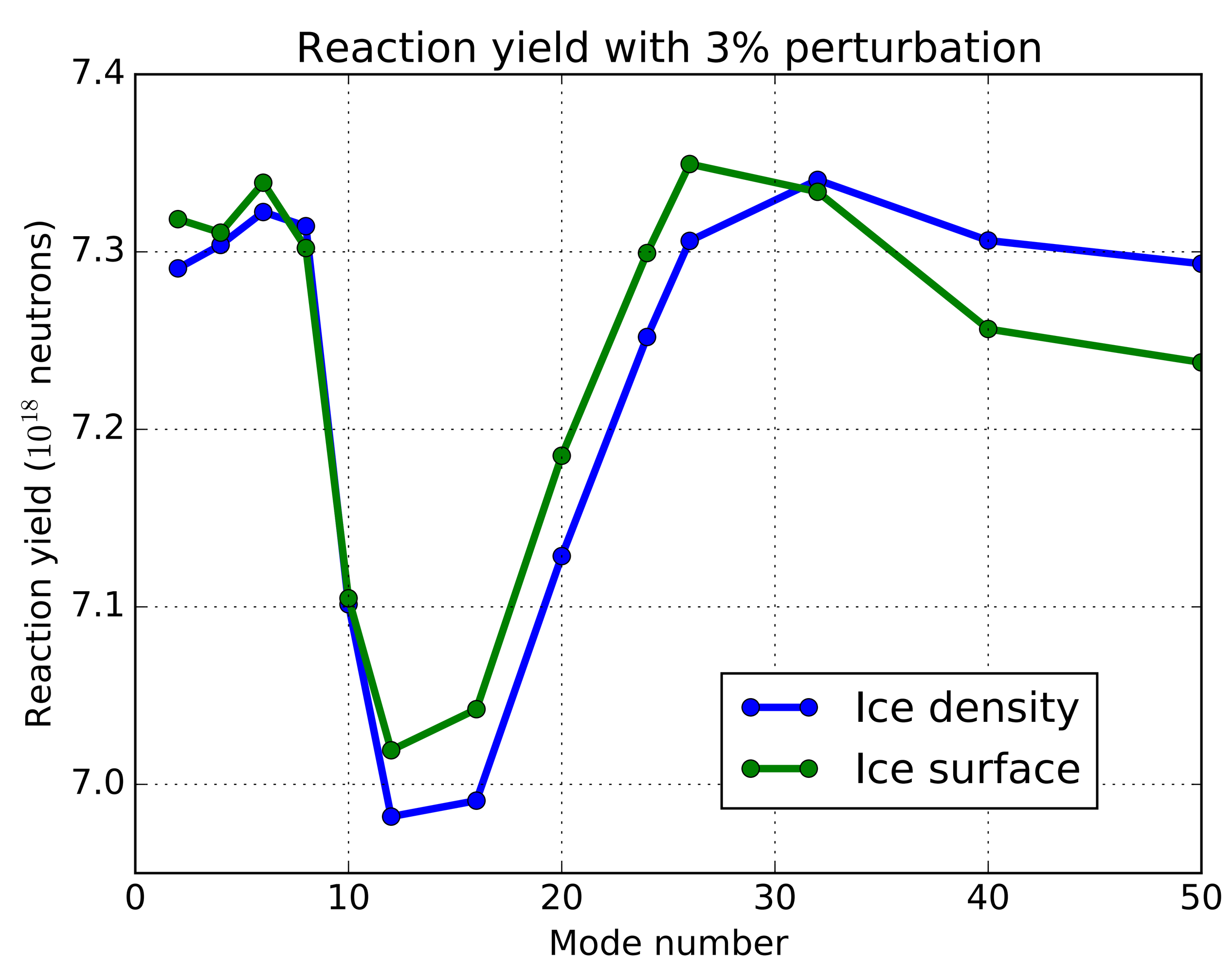

Fig. 1: Impact of a 3% perturbation of ice surface and density on implosion yield.

Growth Factor

The growth factor shows that ice surface and density perturbations grow similarly at low modes, and both grow much less than ablator perturbations do (see Fig. 2). The maximum growth for both surface and density occur at mode 16. This reason that mode 12 had a lower reaction yield is likely that lower modes remain linear longer and are able to grow more as a result.

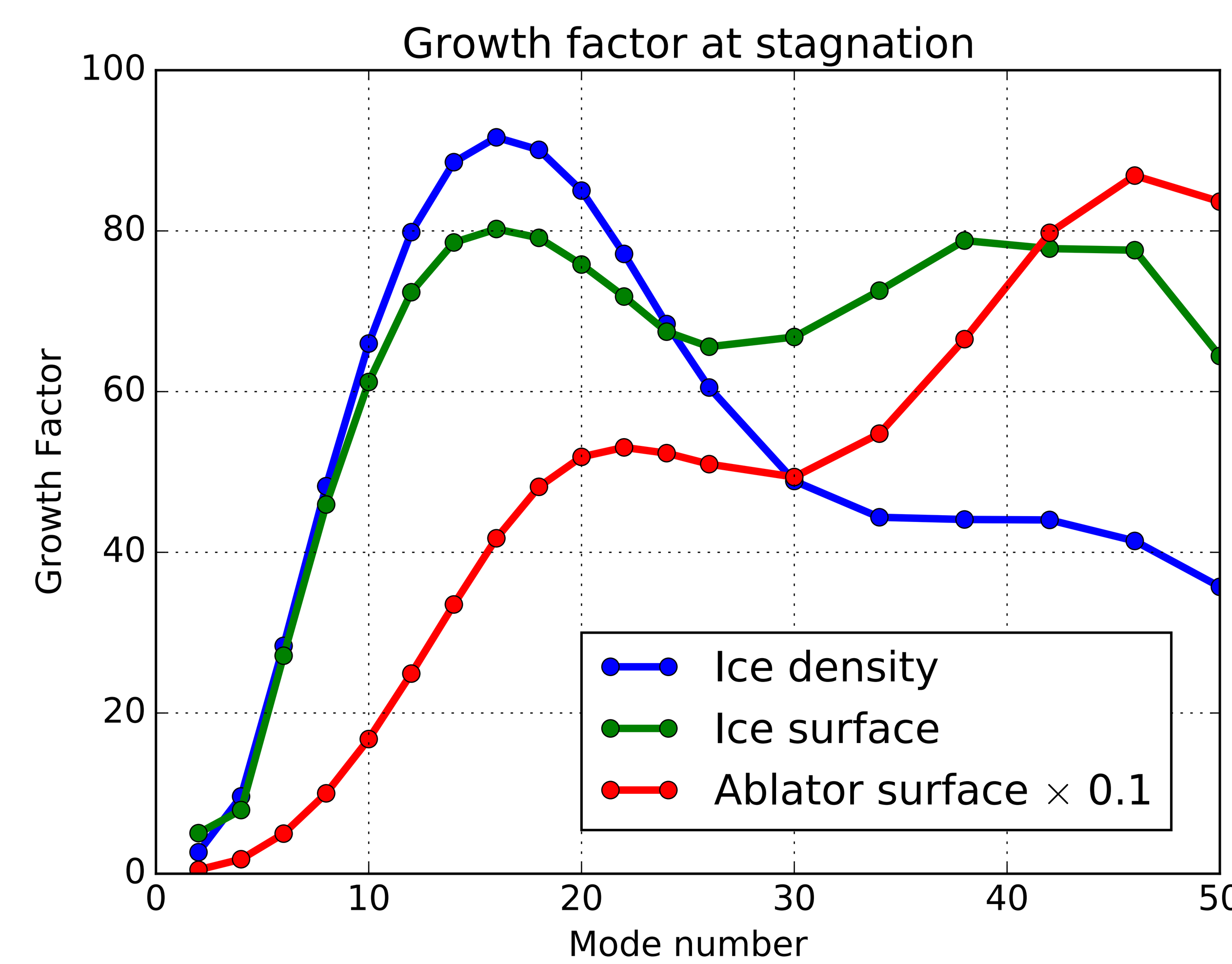

Fig. 2: Growth factor of ice and ablator perturbations.

Ablator Compensation

Deliberate surface and density perturbations in the ablator significantly reduced ice perturbation growth. The two perturbations nearly completely cancelled when the capsule reached stagnation. This result was consistent for both surface and density perturbations in the ice, even up to 50% amplitude (see Fig. 3).

Ablator Compensation of inner ice surface perturbation

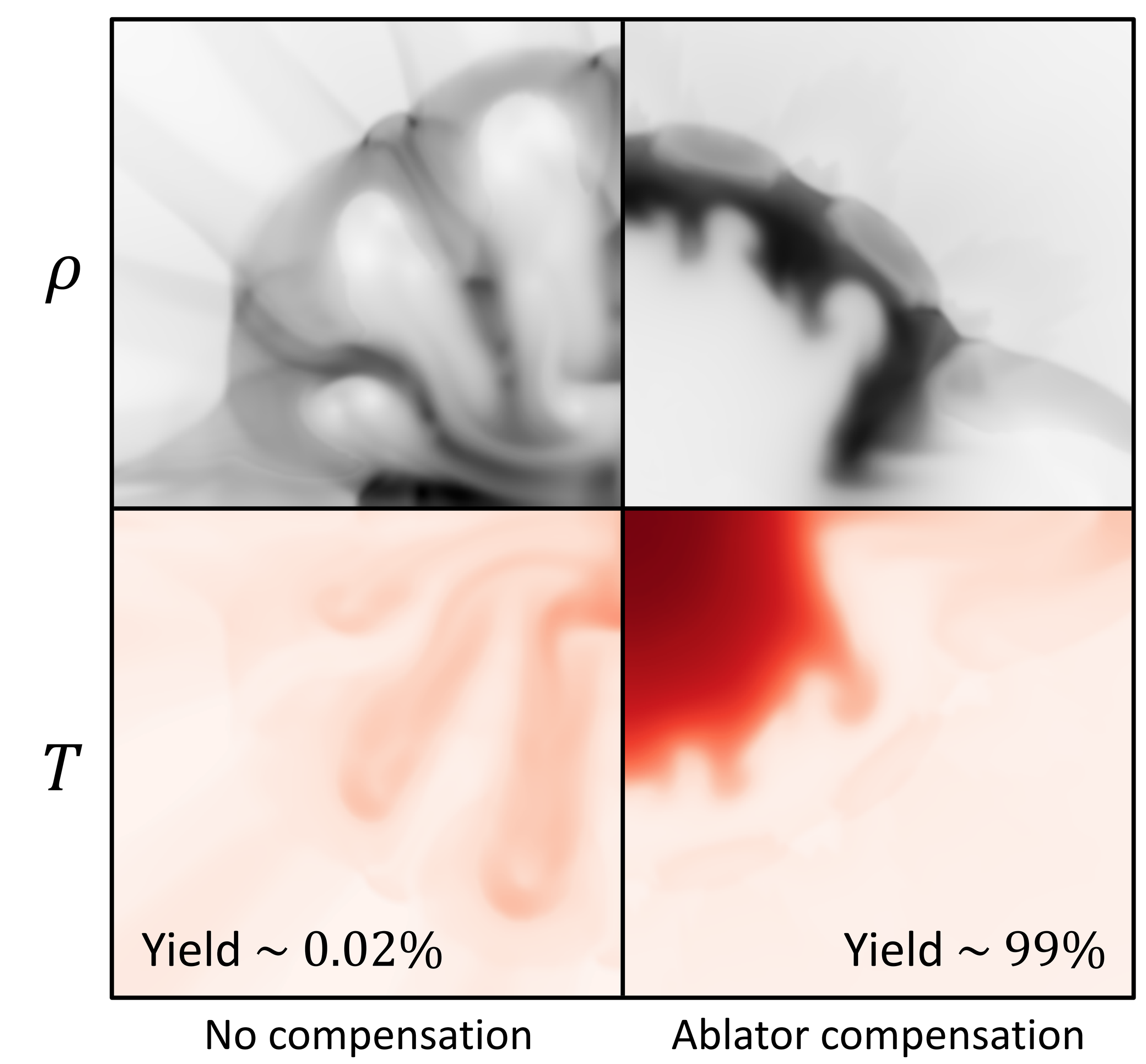

Fig. 3: Comparison at stagnation of a 50% ice surface perturbation without (left) and with (right) an accompanying 0.72% ablator surface perturbation of opposite phase.

Future Work

- Measuring growth factor for higher mode numbers
- Exploring radial dependence of growth from ice density seeds
- Investigating the effect of bubbles in the ice
- Identifying which manufactured ablator perturbations could better mitigate ice perturbations

References

1. D. S. Clark et al., Phys. Plasmas **20**, 056318 (2013)
2. S. W. Haan et al., Phys. Plasmas **22**, 032708 (2015)
3. D. S. Clark et al., Phys. Plasmas **23**, 056302 (2016)
4. R. Tommasini, Phys. Plasmas **22**, 056315 (2015)

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